2.4 Raising the Rockies

Figure C2.35: Mount Michener has complex folds within its beds of shale and limestone.

The Rocky Mountains are truly spectacular. Your eyes may at first be drawn to the peaks and the overall beauty of the surrounding landscape. As you take in the view, your eyes may start to notice some of the finer details. For example, you may begin to appreciate the beauty of the patterns within the rock layers. Note the complex folds within the beds of shale and limestone in the photo of Mount Michener in Figure C2.35.

You earlier discovered that shale is a sedimentary rock originally laid down in nearly horizontal layers of fine sediment at the bottom of tropical seas. The fossil evidence from sites such as the Burgess Shale supports this idea. So, how does the floor of a tropical sea get raised up to become a mountain? How can such massive layers of rock become folded into such intricate designs? What forces could produce these incredible effects? The answers have a lot to do with plate tectonics. In this lesson you'll see that there is much in common with the mechanisms that caused both The Alaska Earthquake of 1964 and the raising of the Rocky Mountains about 170 million years ago.

Locating Plate Boundaries

Before returning to the Alberta of ancient times, it is important to develop a better understanding of plate tectonics and the mechanisms capable of building mountains. Finding the current boundaries of Earth's tectonic plates is a good place to begin.

It was the years of built-up stress between the Pacific Plate and the North American Plate that gradually accumulated a huge amount of stored energy along the southern coast of Alaska in the early 1960s. The sudden release of this energy caused The Alaska Earthquake of 1964 in March of that year. Since earthquakes usually occur at the boundaries of crustal plates, it makes sense to plot the locations of major earthquakes on a world map to locate the edges of the major plates.

A case can also be made for plotting volcanoes on a world map. In Chapter 1, it was stated that Earth's crust is comprised of a series of rigid crustal plates that move over the asthenosphere—a zone of partially molten rock. The asthenosphere is the source of magma for volcanoes. Volcanoes usually occur at a boundary where two plates move apart, or at a boundary where one plate is pushed under another plate. Even though volcanoes sometimes occur at places not close to plate boundaries, plotting the locations of the world's active volcanoes can still provide valuable insights for mapping out the edges of crustal plates. In "Mapping the Edges of Crustal Plates," you will have an opportunity to use the Internet to collect information about the locations of active volcanoes and earthquakes.

Utilizing Technology

Mapping the Edges of Crustal Plates

Purpose

You will use the Internet to determine the locations of active volcanoes and earthquakes. You will record your results on a world map and label the plates from a provided list of names.

Materials

You will need access to a computer. You will also need a copy of the "World Map" on the Science 20 Textbook CD to record the locations of volcanoes and earthquakes.

You may decide to print this map and record your findings on the print copy with different pens—one colour for earthquakes, another for volcanoes. Alternatively, you could electronically paste a copy of the map into another software application that would allow you to electronically add your colour-coded findings to the map before printing your finished map.

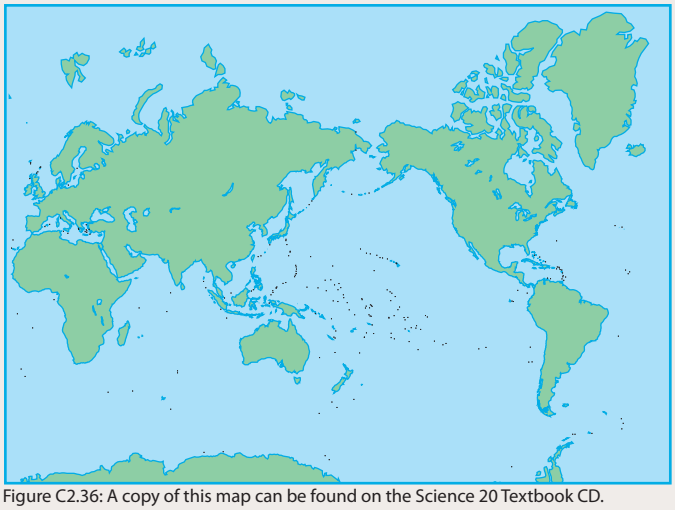


Figure C2.36: A copy of this map can be found on the Science 20 Textbook CD.

Science Skills

- ✓ Initiating and Planning
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Procedure

step 1: As with any Internet search, your success will largely depend upon your ability to choose appropriate combinations of key words to enter into the search engine. You should also consider the time frame you used to limit the scope of your search. For example, do you search for earthquakes that occurred in the last year, the last five years, or the last 100 years?

step 2: Transfer the results of your Internet search to your map by using one colour to represent an earthquake and another for the location of a volcano.

step 3: You should start to notice that the dots will form a pattern of lines that corresponds to the edges of the crustal plates. If the dots are too far apart and too random to form a clear pattern, return to step 1 and modify your search techniques either by changing the key words or by modifying the time line in your search. On the map you created in step 2, record the modifications that improved your results.

step 4: Repeat steps 1 to 3 until you have a clear pattern of plate boundaries.

Analysis

1. Your map now needs labels to be added for the larger plates. Select your labels from the following list:

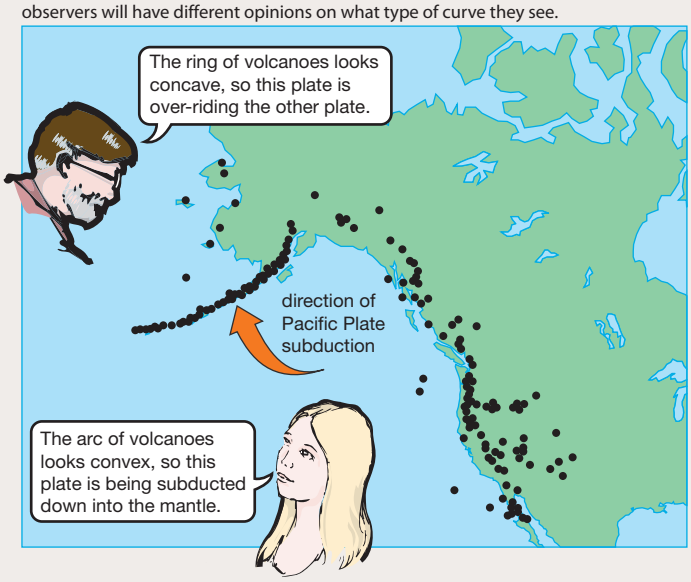
   - North American Plate
   - South American Plate
   - Pacific Plate
   - African Plate
   - Antarctic Plate
   - Indo-Australian Plate
   - Eurasian Plate
   - Arabian Plate

   There are many smaller plates, but many do not have recognizable names. For example, the Nazca Plate lies to the west of the South American Plate, and the Cocos Plate is west of Central America. Add these names to your map.

2. Lines of volcanoes are generally found in places where one plate is being pushed under another plate. The volcanoes are located on the over-riding plate. As shown in Figure C2.37 of Alaska's Aleutian Islands, an arrow can be added to show the direction of the down-going Pacific Plate relative to the over-riding North American Plate. A pattern has been noticed by geologists concerning the type of curve in the arc of volcanoes. If an observer looks at the arc and it appears convex—the middle of the curve is the closest part to the person—then that observer is on the down-riding plate being subducted. If an observer looks at the arc and it appears concave—the middle of the curve is the farthest part from the person—then that observer is on the over-riding plate.

   Use this information to add arrows that show where the northern section of the Pacific Plate is being subducted.

Figure C2.37: Depending on where they're viewing an arc of volcanoes from, observers will have different opinions on what type of curve they see.


The ring of volcanoes looks concave, so this plate is over-riding the other plate.
direction of Pacific Plate subduction
The arc of volcanoes looks convex, so this plate is being subducted down into the mantle.

3. Refer to your answer to question 2. Infer a reason why the perimeter of the North Pacific is called the ring of fire. Does the direction of the arrows imply the Pacific Ocean is growing or shrinking?

Evaluation

4. It is helpful to share your findings with other students. Compare your map with the work of other students. Are there major differences in the labelled maps produced? If you had to do a similar exercise again, what would you have done differently?

DID YOU KNOW?

The Global Positioning System (GPS) can be used to very accurately determine your position on Earth's surface. The United States Geological Survey uses GPS in Southern California and other places to measure movement along the many fault lines that mark the edge of the tectonic plates. GPS is also used near volcanoes to record the uplifting of surface rock due to the motion of magma deep beneath the surface.

Further Evidence for Plate Tectonics

In Chapter 1 you saw how paleomagnetism from the bottom of the Atlantic Ocean provided evidence for the theory of plate tectonics. In "Mapping the Edges of Crustal Plates," you saw how the location of earthquakes and volcanoes can produce a world map showing crustal plate boundaries.

Pangaea: a single supercontinent that formed in the late Paleozoic Era

Some of the strongest evidence for the theory of plate tectonics emerges from the end of the Paleozoic Era. Geologists think Earth's land masses formed a single gigantic continent called **Pangaea** at that time. The name *Pangaea* was coined by Alfred Wegener in 1915 when he first proposed his theory of continental drift, which is a forerunner to the theory of plate tectonics.

In "Plate Tectonics" on page 355, you will consolidate your understanding of plate tectonics by watching an applet on the Science 20 Textbook CD.

Utilizing Technology

Plate Tectonics

Purpose

You will have an opportunity to collect further evidence that supports the theory of plate tectonics by watching "Plate Tectonics" on the Science 20 Textbook CD.

Science Skills

✓ Performing and Recording

Procedure

Preview the questions in "Analysis" before watching the applet. When information presented addresses a particular question, pause the applet and concisely record your answer.

Analysis

1. Sketch a diagram of two continents that illustrates the jigsaw-fit argument for plate tectonics.
2. Identify one example of places on Earth that are now widely separated by ocean waters but were once part of a common geological formation.
3. A mesosaurus was a small freshwater reptile that lived in the late Paleozoic Era. The illustration in Figure C2.38 is an artist's conception of what a mesosaurus might have looked like, based upon the current fossil evidence. Concisely explain how the distribution of mesosaurus fossils supports the existence of both Pangaea and the theory of plate tectonics.

Figure C2.38: A mesosaurus might have looked similar to this.

Alberta Becomes Part of Pangaea

It was during the Devonian Period that beds of organic matter were being laid down to form part of Alberta's future economic wealth in the form of petroleum. In terms of crustal plate movement, the Devonian Period saw Greenland and eastern Canada colliding with northern Europe to begin the process of forming a single northern land mass. Geologists believe the result of this collision was the mountain chain referred to in the "Plate Tectonics" applet. Africa, India, Australia, and South America were already joined as a huge southern land mass. The spaces between the pieces of this ancient continental jigsaw puzzle were closing.

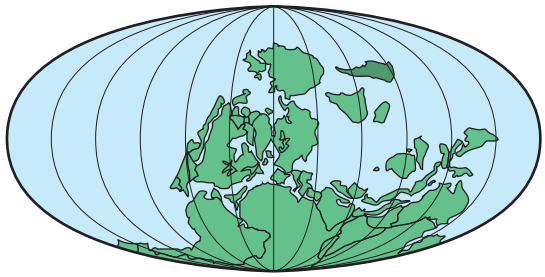


Figure C2.39: Earth may have looked like this 350 million years ago at the beginning of the Carboniferous Period.

As the continents continued to creep toward their eventual merger, the fossil evidence shows that life was continuing to diversify. In the Carboniferous Period, swamps covered much of eastern North America. The lush vegetation that flourished at this time would eventually become the raw material for current coal beds. This vegetation also played a key role in creating an environment to allow insects and the first vertebrates to live on land. The fossil record shows evidence of early amphibians and the first reptiles in the Carboniferous Period—they were small lizard-like creatures. Fossil evidence suggests these early reptiles were the ancestors of future dinosaurs, birds, and mammals.

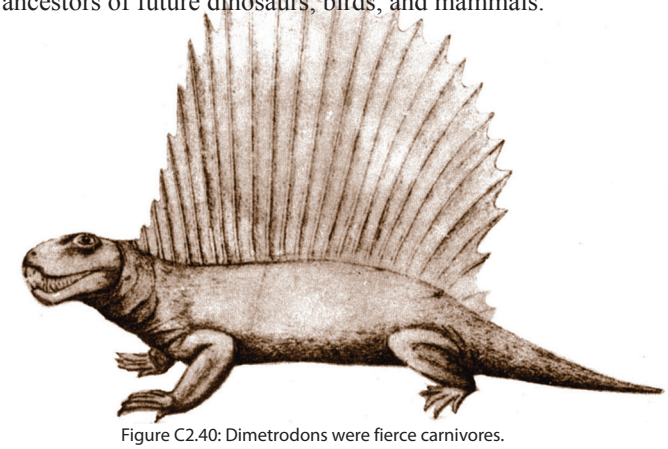


Figure C2.40: Dimetrodons were fierce carnivores.

During the Permian Period, reptiles began to diversify into a wide variety of forms. Fierce carnivores, such as Dimetrodons, were thought to have roamed the equatorial landscape in search of prey. The fossil record shows that life during this time reached a rich level of diversity on both land and sea. By the end of the Permian Period, the huge northern and southern continents had begun to form Pangaea and life was flourishing.

250 million years ago: supercontinent (Pangaea) starts forming

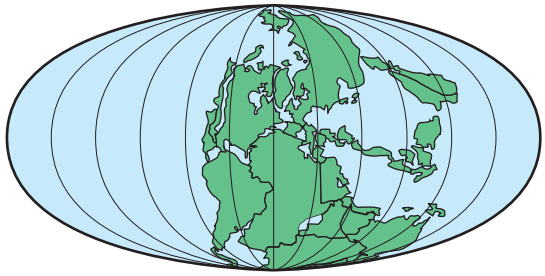


Figure C2.41: Continents may have appeared like this 250 million years ago at the end of the Permian Period.

The Empty Sea

The fossil record contains evidence of six mass extinctions—or large-scale extinctions—in a short time period. The end of the Permian Period 250 million years ago is marked by the greatest extinction of life in the fossil record. It occurred at the end of the Paleozoic Era. At this time, about 90% of ocean species and approximately 70% of land animal species became extinct.

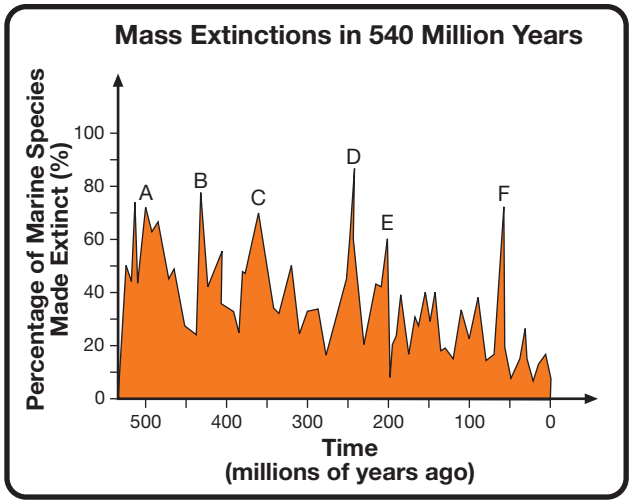


Figure C2.42: The six largest extinction events recorded in the fossil record are identified with the letters A through F.

At the end of the Paleozoic Era, species of animals that had existed since the Cambrian Explosion died or had their numbers greatly reduced. The marine invertebrates were the hardest hit. The simple colonial corals and all trilobite species became extinct. Through the fossil record, scientists have known about the Permian Extinction since the eighteenth century.

Practice

19. Recall your work with the Geological Time Scale in Chapter 1. Is it a coincidence that the largest extinction event occurred at exactly the same time as the end of the Paleozoic Era and the beginning of the Mesozoic Era?
20. Why are trilobites an excellent index fossil for the Paleozoic Era?
21. Use the Geological Time Scale on page 312 to determine the boundaries between eras and periods that correspond to each of the extinction events labelled A through F in Figure C2.42.

Causes of the Permian Extinction

Just what could have caused such a massive extinction event 250 million years ago? There is evidence that widespread glaciation occurred—there are glacial deposits dating back to the Permian Period in some areas of what was Pangaea. If there was a major glaciation at the end of the Permian Period, the sea level would have dropped. Also, shallow water surrounding the land would disappear. There would also be a lower average global temperature.

Another possible cause could be the formation of Pangaea. When the continents collided, the shallow seas between them would be greatly reduced and the coastline area would decrease. This would cause an increasing competition among the organisms in that environment. However, the formation of Pangaea occurred in the middle of the Permian Period. The mass extinctions took place at the end of the Permian Period.

Figure C2.43: This is an artist's representation of an asteroid colliding with Earth.

A deep impact caused by a comet or a very large asteroid colliding with Earth is another possibility for the extinctions. Scientists speculate that this kind of an event would have worldwide implications similar to the aftermath of a nuclear war, such as massive firestorms and enough dust blasted into the atmosphere to block out sunlight for months. The evidence is growing that the mass extinction event that marked the end of the Cretaceous Period—labelled as mass extinction F on Figure C2.42—was primarily caused by such a collision. Researchers are currently looking for evidence that a similar event caused the Permian Extinction.

Geologists have also suggested that the Permian Extinction was due to massive volcanic activity. In what is now Siberia, massive volcanic eruptions and lava flows covered thousands of square kilometres to a depth of more than 3000 m in some locations. Radioactive dating indicates that the eruptions happened about 250 million years ago, which is the same time that the Permian Extinction occurred.

The Effects of Volcanoes

Figure C2.44: Mount Pinatubo, a subduction-related volcano, erupted in the Philippines in 1991.

The twentieth century's largest volcanic eruption took place on Mount Pinatubo in the Philippines, but it was a small disruption compared to the eruptions at the end of the Permian Period. Mount Pinatubo caused a 0.5°C reduction in the average global temperature a year after the eruption because of the more than 20 million tonnes of ash ejected into the atmosphere. The eruptions in ancient Siberia consisted of lava flows and a large amount of ash deposits. Geological evidence indicates that lava erupting from the Siberian volcanoes was very explosive and that these eruptions lasted for hundreds of thousands of years. Given that the ash was believed to be explosive it was likely to have been blasted high into the upper levels of the atmosphere. Sunlight was blocked from reaching the surface, and this caused a global drop in temperatures.

Ash from modern volcanoes has been known to circle Earth for years before settling out. Perhaps the most recent notable climate change caused by a volcano took place in 1815 when Mount Tambora erupted in Indonesia. The next year, 1816, was known as the year without a summer due to a cool spring and summer and the early arrival of fall. The growing season for crops in both Europe and North America was shortened, and some regions suffered a famine.

Practice

22. Identify four of the possible causes of the Permian Extinction.
23. Some geologists suggest that glaciation may, in fact, be a spinoff effect of either the deep impact of a very large meteor or massive Siberian volcanic activity. Explain how each of these causes of the Permian Extinction could also trigger a period of glaciation.
24. Reconsider Figure C2.42. Carefully examine the event labelled D that corresponds to the Permian Extinction and the event labelled F that corresponds to the Cretaceous/Tertiary Mass Extinction.
    a. How does the shape of the graph that describes these mass extinctions suggest that the event was more sudden than gradual in these cases?
    b. Given your answer to question 24.a., which of the possible causes of the Permian Extinction seems most likely?

The Mesozoic Era

Figure C2.45: The dinosaurs were ready to take over.

The Triassic Period was the first part of the Mesozoic Era. During this time, the North American Plate continued its movement to the north and west. As Alberta moved, portions of the plate were alternately above and below sea level. When the Pacific Ocean retreated from Alberta, swampy areas and forests grew in the low-lying coastal areas. Fossil evidence indicates that the first mammals inhabited these forests. Over geological time, vegetation from these forests and swamps became coal deposits.

By the time the Triassic Period ended, Pangaea was coming apart. Geologists believed that this caused sea levels to rise once again and that much of the North American continent was again submerged. Geological evidence suggests that this event, combined with possible collisions by meteorites, triggered another mass extinction that marked the end of the Triassic Period. This corresponds to the mass extinction labelled E on Figure C2.42. A group of creatures took advantage of the vacancies left in the food chain—the age of the dinosaurs was about to begin.

Dinosaurs developed rapidly during the Jurassic Period. Their fossils show the relationship between the land masses during the Mesozoic Era. Fossils of similar, early Jurassic dinosaurs are found all over the world.

Building the Rocky Mountains

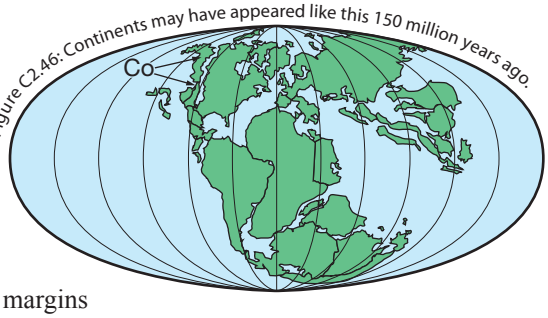
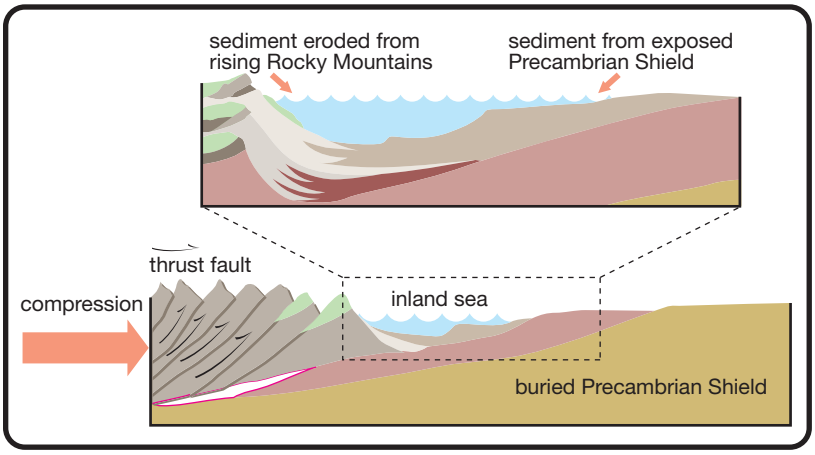


Figure C2.46: Continents may have appeared like this 150 million years ago.

In the middle of the Jurassic Period the break-up of Pangaea continued. North America continued to drift to the west, away from Africa. Arcs of volcanic islands began colliding with the western shore of the North American Plate. These fragments were about to become the western **cordillera** of the North American continent, so they are labelled Co on Figure C2.46.

The tectonic plate carrying these islands was subducted under the westward advances of the North American Plate. This caused the western margins of the North American Plate to be lifted, folded, and thrusted to the east. You should be able to see the similarities between the geological processes at work in present-day southern Alaska and in late Mesozoic Alberta. Geologists suspect that the margins of western Alberta must have been a land of earthquakes and volcanoes at that time.

The slivers of continental crust making up these islands had no place to go, so they became welded to the western coast of North America. Alberta was losing its Pacific coast line, and the continental crust that was to become present-day British Columbia was being added to the North American continent. The volcanic activity that is characteristic of subduction took place as rivers of magma poured onto the surface. The mountain ranges that stretch from western Alberta, and through British Columbia to the Pacific coast, are the remains of several processes. These include raising ocean beds, welding island arcs, and flowing magma from volcanic activity that all began in the Jurassic Period.



cordillera: an extensive chain of mountain ranges that forms the principal range of a continent

170 to 55 million years ago: formation of the Rocky Mountains

Figure C2.47: It took millions of years for the Rocky Mountains to form.

You will notice in Figure C2.47 that an inland sea was created on the east side of the mountains. The great weight of these mountains caused Earth's crust to sag. This allowed ocean water to rush into this sea from both the north and south. Over millions of years, sediment flowed into this sea from the Precambrian Shield to the east and from the rising mountains to the west, but this effect was offset by the gradual sinking of the basin due to the weight of rock sheets being added from the west. In the late Jurassic and Cretaceous periods, these sediments created a vast network of deltas, swamps, and forests that became home to a variety of different dinosaurs. By the late Cretaceous Period, another round of plate collisions on the west coast caused another period of compression.

The net effect was that the inland sea was uplifted and drained; the existing mountains were pushed up even higher; and the main ranges, front ranges, and foothills were formed. Huge faults moved slabs of rock more than 100 km and, in some cases, stacked older rocks on top of younger rocks. The folded rock layers you can see in many of the mountains near Banff and Jasper are the visible result of the compression caused by the collision of the two plates. By the late Cretaceous Period, the Atlantic Ocean was widening and the continents were starting to move toward their modern positions.

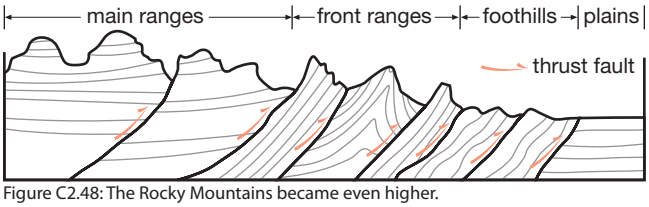


Figure C2.48: The Rocky Mountains became even higher.

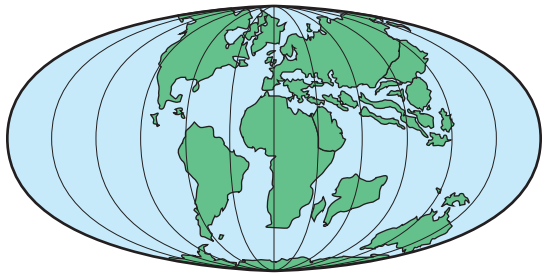


Figure C2.49: Scientists believe Earth's continents were positioned like this during the late Cretaceous Period.

Practice

25. A geologist predicts that the effects of subduction in present-day southern Alaska are likely to have also occurred in Mesozoic Alberta.
    a. Concisely describe the nature of these effects and how they are caused by subduction.
    b. Identify what principle the geologist is using when comparing the geological processes at work in southern Alaska today to those that took place in Mesozoic Alberta.
26. Although the process of subduction was at work, geologists suspect there were some differences between the process currently underway in southern Alaska and the method at work when the Rockies were formed. Figure C2.50 and Figure C2.51 illustrate some of the differences in these two processes.

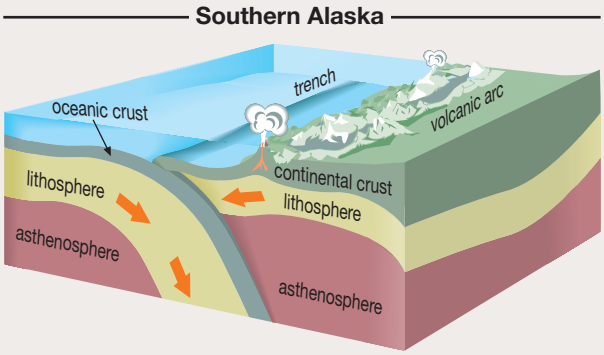


Figure C2.50: This model shows subduction occurring in present-day southern Alaska.

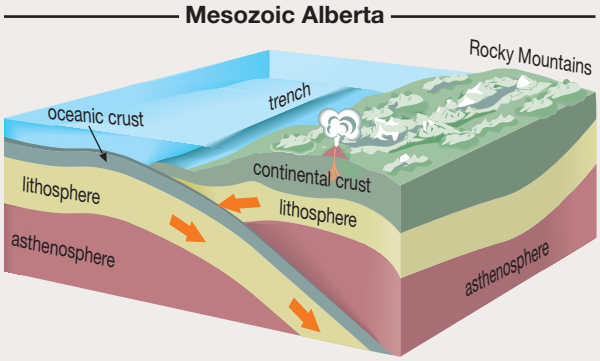


Figure C2.51: This hypothetical model reveals subduction that occurred 70 million years ago in Mesozoic Alberta.

    a. Compare the process of subduction illustrated in both models.
    b. Use features of the models to concisely explain why volcanic activity and mountain building occurred further inland for the building of the Rocky Mountains.

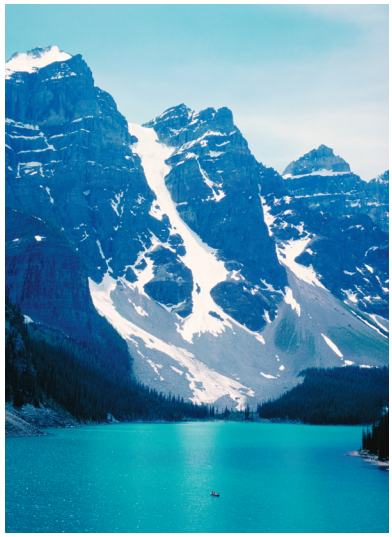
The Cretaceous/Tertiary Mass Extinction

The Cretaceous Period is the last period of the Mesozoic Era. Like the Triassic Period, the Cretaceous Period is marked by a mass extinction. The fossil record indicates that very nearly every land animal with a mass greater than 25 kg became extinct. In the oceans, this marked the end of the line for ammonites and the extinction of nearly half of the different varieties of plankton. The extinction of some plankton species is thought to have caused the collapse of some oceanic food chains.

2.4 Summary

Plate tectonics provide an essential context for many of the significant geological events that took place in both Paleozoic and Mesozoic Alberta. Boundaries between the current positions of the tectonic plates can be determined by plotting the locations of earthquakes and volcanoes on a world map. Geological evidence suggests that in the late Paleozoic Era, Earth's continental crust was fused into a single supercontinent called Pangaea.

When Pangaea began to break up in the Mesozoic Era, the North American Plate drifted toward the west and collided with arcs of volcanic islands riding on the Pacific Plate. The mountainous terrain of British Columbia and western Alberta are thought to be the direct result of these collisions. The fossil record indicates that the formation and eventual break-up of Pangaea occurred during the two largest mass extinctions in Earth's history. The possible causes for these mass extinctions remains an area of intense research.



2.4 Questions

Knowledge

1. Describe the two types of plate boundaries often characterized by volcanic activity.
2. List probable causes for the mass extinction that occurred at the end of the Paleozoic Era. Identify which cause (or causes) is most likely, given data trends on Figure C2.42.
3. Consider the following statement: "It was a mass extinction that gave dinosaurs an opportunity to flourish, and it was a mass extinction that marked their demise." Refer to the "Geological Time Scale" on page 312 as you explain this statement.

Applying Concepts

4. There is a Pacific Plate but no Atlantic Plate. Refer to Pangaea's break-up to explain the origins of the Atlantic Ocean.
5. Earlier in Chapter 2 you saw a photo of the folded layers of shale and limestone on the side of Mount Michener. Concisely explain how these layers of sedimentary rock—originally laid down in horizontal layers at the bottom of a shallow sea—became twisted and intricate designs far above sea level on the side of a mountain.
6. Explain how the Cretaceous/Tertiary Mass Extinction created an opportunity for the rapid diversification of mammals.

Chapter 2 Summary

In this chapter you studied life in the Paleozoic Era, and you learned how the remains of plant and animal life can be preserved for millions of years. You have seen not only how scientists can determine the underground structure of Earth through the application of science and technology, but how they use this information in the search for natural resources. You have seen how seismic waves can be used to locate the epicentre of an earthquake and to provide clues about the internal structure of Earth. In the Mesozoic Era, Alberta was a land of earthquakes and volcanoes as the Rocky Mountains formed due to crustal plates moving under the influence of plate tectonics. The fossil record indicates that life diversified, flourished, and also fell victim to mass extinctions during both of these eras.

In Chapter 3 you will learn about the rise of mammals and the continued cooling of Alberta. These developments led to a series of continental glaciations commonly called the Ice Age. You will see that people now live in what is known as an interglacial period, which is a time between glacial periods. You will be introduced to evidence suggesting that climate, for the first time, may be influenced by people.

Summarize Your Learning

In Chapter 2 you learned many new terms and concepts. Many of the concepts are related, and you will have an easier time recalling them if they are organized into patterns.

Since the patterns have to be meaningful to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" on pages 552 and 553. Choose one of these options to create a summary of the key concepts and important terms in Chapter 2.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. Identify the event referred to as the Cambrian Explosion.
2. Briefly describe the importance of the Burgess Shale fossils.
3. Describe the position of Alberta on Earth's surface during the middle of the Paleozoic Era.
4. Briefly explain how geologists use seismology to determine the underground structures in an area.
5. Identify the supercontinent that existed in the early part of the Mesozoic Era.
6. Dinosaurs became extinct at the end of the _____ Era.
7. Identify two geologic phenomena found near the boundary between two tectonic plates.
8. Identify the process believed to be responsible for sea-floor spreading at ocean ridges.

9. The continents of South America and Africa contain features that suggested to Alfred Wegener that they were once part of the same land mass but later drifted apart. Describe two of these features.
10. Identify the type of seismic wave generated by an earthquake that is the first to reach a seismic station.

Applying Concepts

For Sale!
The World's Oldest Dinosaur Fossil Footprints!
48 million years old!
The age has been verified by carbon-14 dating.
Only $134 + shipping/handling and GST

11. A company obtains your address and sends you the following advertisement. Identify two scientific reasons why you should not purchase this fossil. Support your answer concisely.
12. The fossils of the Burgess Shale were caught in an underwater mud avalanche about 500 million years ago. Today, these fossils are accessible on the slopes of Mount Wapta in the Canadian Rockies. Include a geological time scale as you sketch a concise time line that describes the major geological events that had an effect on this fossil bed over time.
13. A geologist is studying the outcrop in Figure C2.52. You will need to refer to the "Geological Time Scale," and the "Radioactive Decay Curve." These can both be found on page 557.
    a. Determine the age of the basement rocks.

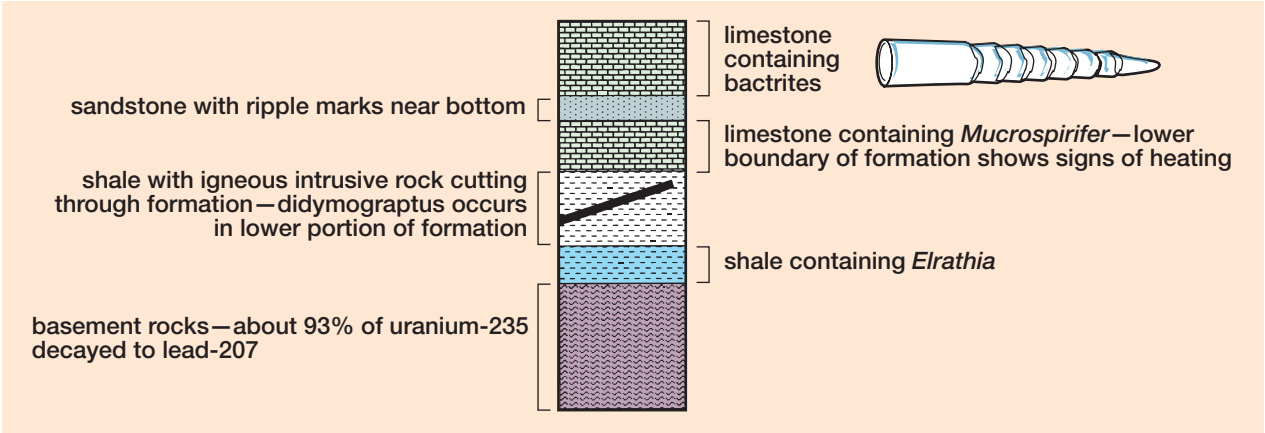
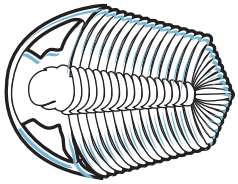
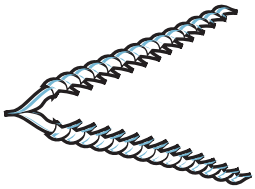

limestone containing bactrites
sandstone with ripple marks near bottom
limestone containing *Mucrospirifer*—lower boundary of formation shows signs of heating
shale with igneous intrusive rock cutting through formation—didymograptus occurs in lower portion of formation
shale containing *Elrathia*
basement rocks—about 93% of uranium-235 decayed to lead-207

Figure C2.52: This is an example of an outcrop.

b. Use this table to determine the age of each of the other rock strata layers.

TABLE OF INDEX FOSSILS

Image of Fossil	Age	Type	Name	Comments
	Middle Cambrian	trilobite	Elrathia	widespread in Western Canada, including Burgess Shale–all trilobite species now extinct
	Ordovician	graptolite	didymograptus	once widespread throughout Earth's oceans—all species of graptolites now extinct
	Middle Devonian	brachiopod	Mucrospirifer	found throughout North America—about 300 species of brachiopods remain
	Permian	mollusc	bactrites	found in Alberta—more than 100 000 species of molluscs alive today

Use the following information to answer questions 14 to 18.

Figure C2.53 shows the sea floor at a typical ocean ridge. Notice that a trench is located on each side of the ocean ridge.

14. Figure C2.53 shows circulation within the mantle. Identify the proper name for this kind of circulation.

15. Identify the name of the geological process acting on the oceanic crust near each of the trenches.

16. Describe what geological phenomena would likely be observed on the continental crust beside each trench.

17. Describe two pieces of evidence that would allow you to measure the rate of sea-floor spreading in this area.

18. Studies have shown that the rate of sea-floor spreading and subduction are about the same. Why must this be so?

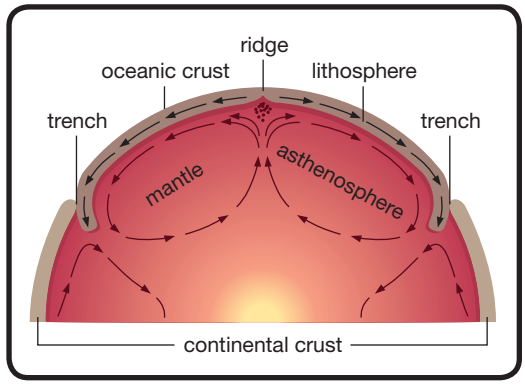


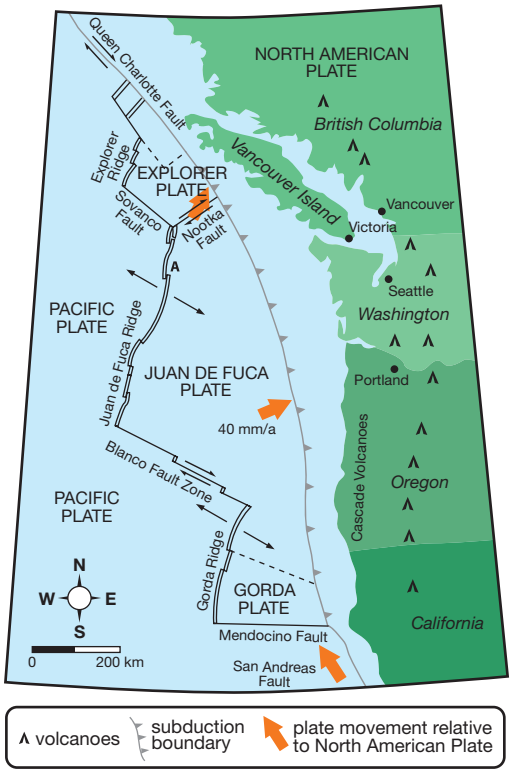
Figure C2.53: The sea floor of a typical ocean ridge is illustrated.

Use the "Tectonic Map of the West Coast" on page 363 to answer questions 19 to 23.

19. Consider the boundary between the Juan de Fuca Plate and the North American Plate. Identify which plate is the subducting plate and which one is the over-riding plate. Concisely support your answer.

20. Locate the Juan de Fuca Ridge. Note the small arrows that indicate the Pacific Plate is moving to the northwest, while the Juan de Fuca Plate is moving to the southeast. Describe the motion of the mantle material below the Juan de Fuca Ridge.

Tectonic Map of the West Coast



Use the following additional information to help answer questions 21 to 23.

Figure C2.54 shows the same details of the "Tectonic Map of the West Coast" as a cross section, instead of as a flat map. The cross-section map shown is an imaginary 200-km-deep cut into Earth. The cut runs along a line that extends the two arrows on the flat map of the Juan de Fuca Ridge all the way to the North American continent just south of Portland, Oregon. However, this cross-sectional diagram is missing labels, which have been identified with the letters in the boxes.

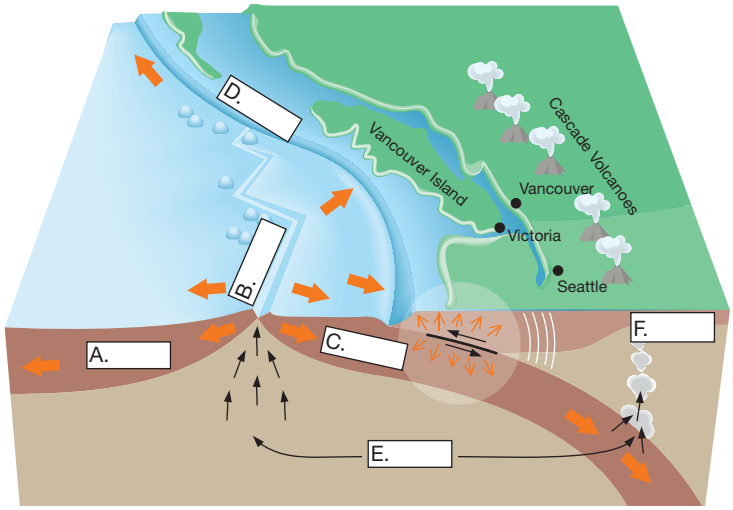


Figure C2.54: An imaginary cross-section map gives another view of tectonic plates.

21. Which letters on Figure C2.54 should be labelled North American Plate, Juan de Fuca Plate, and Pacific Plate? Answer by matching each of these labels to the correct letter.

22. Which letters on Figure C2.54 should be labelled Juan de Fuca Ridge, trench, and sources of molten rock? Answer by matching each of these labels to the correct letter.

23. The labels missing from Figure C2.54 are the focus and epicentre of a major earthquake. Many geologists think this region actually has a risk of experiencing a significant earthquake. Investigations have led geologists to conclude that major earthquakes do occur in this region, but they are separated by hundreds of years. The last great earthquake was The Cascadia Megathrust Earthquake of 1700.

a. One piece of evidence for a great earthquake occurring near Vancouver Island in 1700 was found in historical records from communities on the east coast of Japan. Using your knowledge of The Alaska Earthquake of 1964, explain the most likely method for The Cascadia Megathrust Earthquake of 1700 to affect Japanese coastal villages.

b. Return to the "Tectonic Map of the West Coast." Identify the average speed for the Juan de Fuca Plate moving toward the North American Plate.

c. Use your answer from question 23.b. to determine the total distance (in metres) the Juan de Fuca Plate moved between the years of 1700 and 2000.

d. Juan de Fuca Plate motion continues to store energy in the elastic bending and buckling of the continental crust. What happens when this energy is suddenly released?

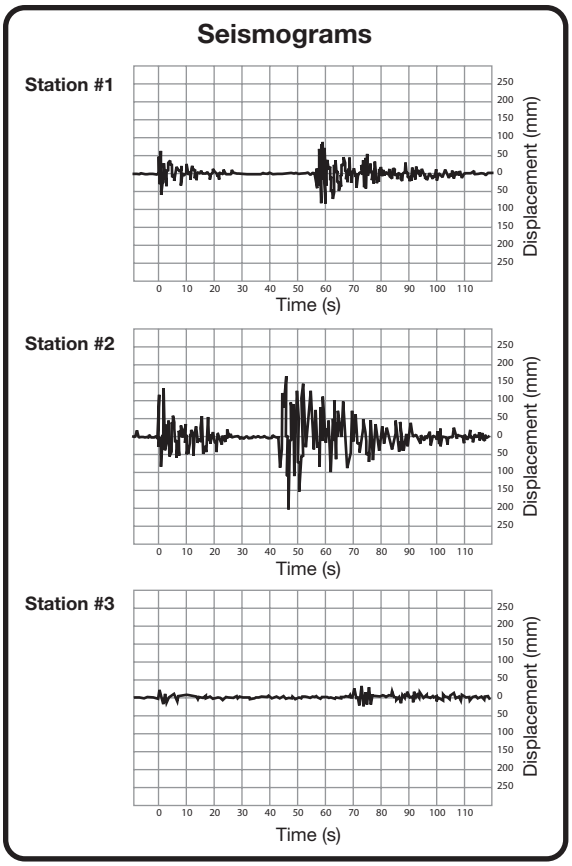
e. During The Alaska Earthquake of 1964, the part of the North American Plate being flexed by the subduction of the Pacific Plate sprang back an average distance of 9 m. If the North American Plate around Vancouver Island were to spring back the distance that you calculated in question 23.c., determine if this earthquake would likely be smaller or larger than The Alaska Earthquake of 1964.

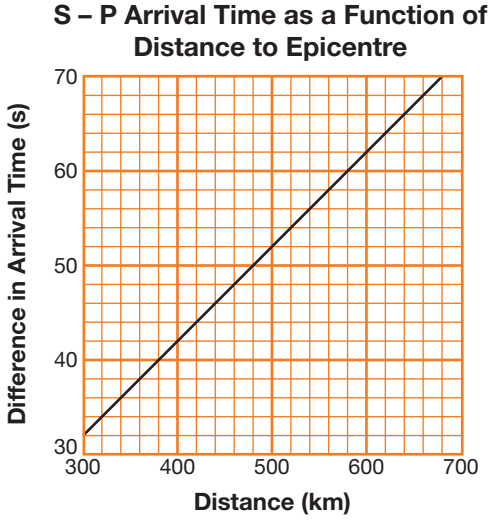
f. Geologists estimate that the average time between major earthquakes that occur at the boundary between the Juan de Fuca Plate and the North American Plate is about 500 years. Refer to your previous answers to explain why a long time interval between earthquakes means that when an earthquake does occur, it will tend to be a very large one.

g. Use the Internet to find out more about The Cascadia Megathrust Earthquake of 1700. What Richter magnitude number has been estimated for this event?

Use Figure C2.55 to answer questions 24 to 28.

An earthquake was recorded by three seismic stations. The seismographs at each station generated the seismograms in Figure C2.55 to describe this earthquake. The data on these seismograms can be used to determine the epicentre of an earthquake. This information can also be used to find the Richter magnitude number of the earthquake by using the S-P graph and the Richter nomogram.





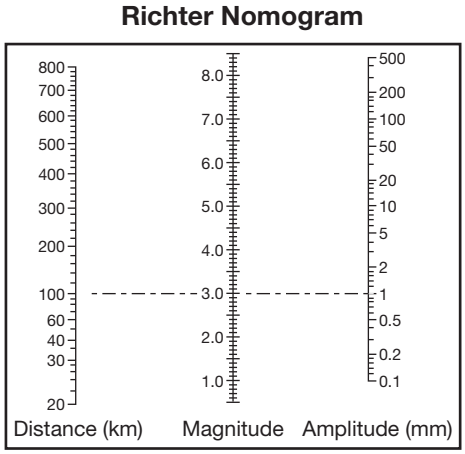


Figure C2.55: Seismograms, an S–P graph, and a nomogram are all used to determine earthquake information.

24. These seismograms show two waves arriving at each seismic station.

- **a.** Identify which type of seismic wave is the first to arrive at each station.
- **b.** Identify which type of seismic wave is the second to arrive.
- **c.** Identify which type of seismic wave is not represented on these seismograms.

25. Determine the distance from the epicentre to each seismic station by using the seismogram for each station and the S-P graph.

26. By using your answer from question 25, it is possible to rank the distance of each seismic wave to the epicentre from closest to farthest. Concisely explain which feature on each of the seismograms confirms the order.

27. Explain how you would use a map and the distance from each seismic station to the epicentre to determine the location of the epicentre on a map.

28. Use the nomogram in Figure C2.55 to determine the Richter magnitude for this earthquake.

29. In Chapter 1 you began a time line to record key events that occurred in each era of geological time. Review Chapter 1 to ensure that you have included the significant entries from the Paleozoic and Mesozoic eras.

Use the following information to answer questions 30 to 33.

The Extinction Essays: A Research, Reporting, and Analysis Activity

The next questions are part of a self-directed activity in which you will research the most current theories that attempt to explain the Cretaceous/Tertiary Mass Extinction. This was the event that marked the disappearance of dinosaurs from the fossil record. In this chapter you were introduced to some of the theories that attempted to explain this mass extinction. You will now have an opportunity to extend your learning by exploring the latest research on three of these theories.

The following questions that outline this activity have three distinct phases:

- The first step is a research phase in which you investigate each of three distinct theories that attempt to explain the Cretaceous/Tertiary Mass Extinction.
- Next is a reporting phase where you write three concise essays to summarize key concepts that support each theory.
- The final phase involves an analysis of the three theories you investigated. You will write a fourth essay stating which of the three theories you think is most likely.

The standard for evaluating the research phase is as follows.

Score	Scoring Description
Standard of Excellence (4 marks)	The response demonstrates that each of the theories was thoroughly researched using several sources of information for each theory. The research identifies the relevant scientific evidence that supports each theory. The subsequent organization of the researched material allows for a thorough and accurate description of both the arguments that support each theory and the shortcomings of each theory.
Acceptable Standard (2 marks)	The response demonstrates that each of the theories was researched using more than one source of information for each theory. The research identifies some of the relevant scientific evidence that supports each theory. The subsequent organization of the researched material allows for a description of at least one argument that supports each theory and at least one shortcoming for each theory.

The standard for the essays is as follows.

Score	Scoring Description
Standard of Excellence (4 marks)	The response is well organized and accurately addresses the major points of the question. The student uses complete sentences that effectively employ scientific vocabulary. Relevant scientific and technological concepts and examples are identified, and interrelationships are explicit. The descriptions and/or explanations of these concepts reflect a clear and thorough understanding and consistent logical thought. When appropriate, descriptions and/or explanations are enhanced by suitable organizers, such as comparisons or graphics including diagrams, graphs, and tables.
Acceptable Standard (2 marks)	The response addresses most major points. The student uses complete sentences but is inconsistent in the employment of appropriate scientific vocabulary and graphic organizers. Relevant scientific and technological concepts and examples are identified, and interrelationships are shown. The descriptions and/or explanations of these concepts may be disorganized but demonstrate a correct understanding of the concepts.

30. Choose a theory that explains the Cretaceous/Tertiary Mass Extinction.

a. Use the Internet to research the answers to the following three questions:
(a) What is the basic premise of this theory?
(b) What scientific processes are involved in this theory?
(c) How does this theory explain the Cretaceous/Tertiary Mass Extinction?

b. Use your information from 30.a. to construct an essay that addresses these three questions.

31. Repeat the process outlined in question 30 to complete the research and construct an essay for the second theory.

32. Repeat the process outlined in question 30 to complete the research and construct an essay for the third theory.

33. Combine your answers from questions 30 to 32 to determine which theory you think is the most likely. Compare and contrast all three theories. Answer in the form of an essay.